#18
10/24/03

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Serial No. 09/870,428 Filed May 30, 2001
(Attorney Docket No. GP-301083)

Thomas A. Slopsema
Randall S. Beikmann
Paul A. Bauerle
Julie S. Fuller
Stuart R. Smith
Helmut L. Oswald

Group 3747

METHODS AND APPARATUS FOR CONTROLLING A SHUTDOWN OF AN INTERNAL COMBUSTION ENGINE

Examiner Castro, Arnold

AFFIDAVIT UNDER 37 CFR 1.131

Commissioner for Patents
P.O. Box 1450
Alexandria VA 22313-1450

Helmut L. Oswald, being duly sworn, deposes and says:

1. I am an inventor of claims 1-24 of the patent application identified above and an inventor of the subject matter described and claimed therein.

2. Prior to August 1, 2000, having earlier conceived of the idea for the invention "Methods and Apparatus for Controlling a Shutdown of an Internal Combustion Engine," and with due diligence, I reduced the invention as evidenced by the attached invention disclosure form and documentation. The dates have been redacted from the invention disclosure and documentation.

H. Oswald
Helmut L. Oswald

General Motors Corporation
Legal Staff
300 Renaissance Center
Mail Code 482-C23-B21
PO Box 300
Detroit MI 48265-3000

Attachment

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Thomas A. Slopsema, being duly sworn, deposes and says:

Randall S. Beikmann, being duly sworn, deposes and says:

Paul A. Bauerle, being duly sworn, deposes and says:

Julie S. Fuller, being duly sworn, deposes and says:

Stuart R. Smith, being duly sworn, deposes and says:

1. I am an inventor of claims 1-24 of the patent application identified above and an inventor of the subject matter described and claimed therein.

2. Prior to August 1, 2000, having earlier conceived of the idea for the invention "Methods and Apparatus for Controlling a Shutdown of an Internal Combustion Engine," and with due diligence, I reduced the invention as evidenced by the attached invention disclosure form and documentation. The dates have been redacted from the invention disclosure and documentation.

Thomas A. Slopsema

Randall S. Beikmann

Paul A. Bauerle

Julie S. Fuller

Stuart R. Smith

Subscribed and sworn to before me this 25TH day of July, 2003.

Notary Public

General Motors Corporation
Legal Staff
300 Renaissance Center
Mail Code 482-C23-B21
PO Box 300
Detroit MI 48265-3000

Attachment

STEPHEN R. KORNBLUM
NOTARY PUBLIC OAKLAND CO., MI
MY COMMISSION EXPIRES Apr 4, 2007

Paul A. Bauerle

Julie S. Fuller

Stuart R. Smith

Subscribed and sworn to before me this 30 day of September, 2003.

Notary Public

General Motors Corporation
Legal Staff
300 Renaissance Center
Mail Code 482-C23-B21
PO Box 300
Detroit MI 48265-3000

Attachment

Subscribed and sworn to before me,
in my presence this 30 day of Sept., 2003.
a Notary Public in and for the county of Larimer
and the State of Colorado

(Signature of Notary)

My Commission Expires 2-4-13, 2006.

WILLIAM FUERSTENBERGER NOTARY PUBLIC STATE OF COLORADO 9-30-03

GENERAL MOTORS CORPORATION

File No. GP-301083
PTE 2000111

RECEIVED
BY: S. L. Kamble

RECORD OF INVENTION
Part 1

This Record of Invention (Part 1) provides for the disclosure of your invention with the minimum detail necessary for an initial evaluation by a Review Board consisting of engineering/business management & Legal Staff personnel. The Review Board will consider novelty and competitive significance in determining the appropriate disposition of your invention. If the Review Board decides to pursue a patent on your invention, you will be required to prepare a Record of Invention (Part 2) containing the detailed disclosure necessary to enable the preparation of a patent application. If the Review Board decides to publish of your invention, you will be provided instructions for preparing a disclosure for publication.

Invention Title: Engine Shut Down Shudder Fix

Inventor #1

Name: Thomas (First Name) A. (Middle Initial) Slopsema (Last Name) Citizen of: USA

Social Security No. 383-50-3185 GM Employee: ☒ Yes ☐ No ☒ Salary ☐ Hourly ☐ Contract

Home Address: 2595 Graduate Way (Street) Holt, Mi (City and State) 48842-9773 (Zip Code)

GM Unit: Powertrain Group GM Phone (8)-341-1637 (Centrex Number) 248 676-1637 (Area Code) + Number

GM Address: 3300 General Motors Rd Bldg 94 Mail 483-394-126 FAX Number: (8)-341-7851 (Centrex Number)

Non-GM Employer: Phone No. (Area Code) + Number

Non-GM Employer Address: (Street) (City and State) (Zip Code)

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GENERAL MOTORS CORPORATION

LEGAL STAFF

Inventor #2

Name: Randall (First Name) S (Middle Initial) Beikmann (Last Name) Citizen of: USA

Social Security No. 515-76-8341 GM Employee: ☒ Yes ☐ No ☒ Salary ☐ Hourly ☐ Contract

Home Address: 841 Nelson St. (Street) Brighton, MI (City and State) 48116 (Zip Code)

GM Unit: Powertrain Group GM Phone (8)-341-3793 (Centrex Number) (248) 684-3793 (Area Code) + Number)

GM Address: 3300 General Motors Road, Bldg. 94 Mail 483-394-126 FAX Number: (8)-341-7851 (Centrex Number)

Non-GM Employer: Phone No. (Area Code) + Number

Non-GM Employer Address: (Street) (City and State) (Zip Code)

Inventor #3 *

Name: (First Name) (Middle Initial) (Last Name) Citizen of:

Social Security No. GM Employee: ☐ Yes ☐ No ☐ Salary ☐ Hourly ☐ Contract

Home Address: (Street) (City and State) (Zip Code)

GM Unit: GM Phone (8)- (Centrex Number) (Area Code) + Number)

GM Address: Mail FAX Number: (8)- (Centrex Number)

Non-GM Employer: Phone No. (Area Code) + Number

Non-GM Employer Address: (Street) (City and State) (Zip Code)

* If there are more than three (3) inventors on a ROI use the template at the end of this form.

Answer the following questions, completing all of them to the best of your knowledge.

1. This invention has been or is expected to be disclosed outside GM on: _____

2. This invention has been used or is committed to be used in production on: _____

3. This invention has been offered for sale outside GM on: no

4. Was this invention made while working on a Government Contract? ☐ Yes ☒ No

   If yes, identify the government Contract No. _____

5. Identify the product or process in which the invention is incorporated: L5 Engine with Electronic Throt Control

6. Provide enough detail of the specific new features, components, or steps that form the invention to enable a general understanding of its technical content and novelty. The description should be referenced by numerals to an attached drawing, (if appropriate), that highlights the specific features, components, or steps of the invention including the environment or assembly in which the invention is incorporated.

   This invention is a new sequence by which to bring a spark ignition engine to a stop to provide a quick, smooth shut down event. This new sequence greatly reduces the fundamental physical cause of engine shudder during shutdown.

   Engine shut down is the event of bringing the engine speed from idle, or above idle down to zero speed (full stop). This event is initiated in a vehicle by switching the ignition key to "off" position. In current fuel injection spark ignited engine vehicles, switching the ignition key to "off" stops the fuel injectors and the spark. Without fuel and spark, the engine rpm drops to zero over some timespan.

   This new sequence simply requires the throttle blade to be fully closed during shutoff. This algorithm is especially critical on engines with Electronic Throttle Contol (ETC), which have built-in partially open throttle position default modes.

   Current ETC engines allow the throttle blade to go open as far as 20% (or more) when the engine is keyed off. At low engine speeds this throttle blade opening allows manifold vacuum to decrease (manifold pressure to increase), allowing a greater charge of fresh air into the cylinders, and thereby causing the pistons to compress full charges of air during the shut down event. Greater torque pulses are exerted on the engine block, and the engine shutdown takes longer due to lack of throttling losses. Depending upon the engine configuration, this situation can cause a significant back and forth engine roll at a frequency corresponding to the engine firing order, which subjectively feels like a major engine or vehicle shudder.

   This invention defines how to fundamentally eliminate this engine shudder phenomenon by fully closing the throttle blade to maximize intake manifold vacuum during shutdown, which minimizes air compression in the cylinders, and shortens the engine shut down event time.

   This invention was developed by Tom Slopsema and Randy Beikmann on at Building 94, NVC, Milford Proving Grounds, while working on the shut down shudder problem on L5 truck 190P2P03.

7. What are the competitive benefits to be realized through the use of this invention? For example: cost, quality and performance improvements, new features and products, etc.
   1. *Increases customer satisfaction with the vehicle*
   2. *Decreases customer complaints with the vehicle*
   3. *Eliminates need for other more costly fixes such as dual mode flywheel*

8. To the extent known, what alternatives exist for accomplishing substantially the same result of this invention?
   Dual mode flywheel helps, no other full fix known.

9. What are the technical benefits obtained, problems solved, and advantages realized over the alternatives identified in Item #8?
   Lower cost, lower mass, better fix. Solves the root cause of the problem without introducing other drawbacks.

10. What is the state of development of this invention?
    This sequence has been demonstrated with dramatic success to management.

    Implemenation requires keeping the PCM powered up during key off event. Systems group has not fully activated this algorithm in trucks built to date.

I hereby assign this invention to General Motors Corporation and authorize General Motors Corporation to file an application on my behalf.

Thomas A. Slopsema — Thomas A. Slopsema
INVENTOR - SIGNATURE (ALSO, PRINT NAME) DATE

Randall S. Beikmann — Randall S. Beikmann
INVENTOR - SIGNATURE (ALSO, PRINT NAME) DATE

INVENTOR - SIGNATURE (ALSO, PRINT NAME) DATE

This invention was reviewed and understood by me:

Michael J. Grimmer — Michael J. Grimmer
1st WITNESS - SIGNATURE (ALSO PRINT NAME) DATE

Jim Stuckey — Jim Stuckey
2nd WITNESS - SIGNATURE (ALSO, PRINT NAME) DATE

Idle Quality
Current Activities

NVC

- **Finalizing Idle Quality Report**
  - Extensively Reviewed
  - Added Executive Summary to Help Understanding
- **Kettering Fifth-Year Thesis Project**
  - Radu Theyyunni Organizing
  - Aziz Bakar Doing the Work
  - Will Investigate Lower Torque Orders
    - » Simulate Engine Parameter Variations
    - » Obtain Statistical Variation in Torque Orders
    - » Investigate Least Number of Engine Tests for Good Data
- **Idle Quality TGIR Team**
  - Technology Gap Identification and Removal
  - Finding Gaps in Technology
  - Works out of N&V ADV Team (Scott Reilly)

Randy Beikmann
8-341-3793

GM General Motors
Noise & Vibration Center

L5 Shutdown N&V
Rattle and Wiggle

NVC

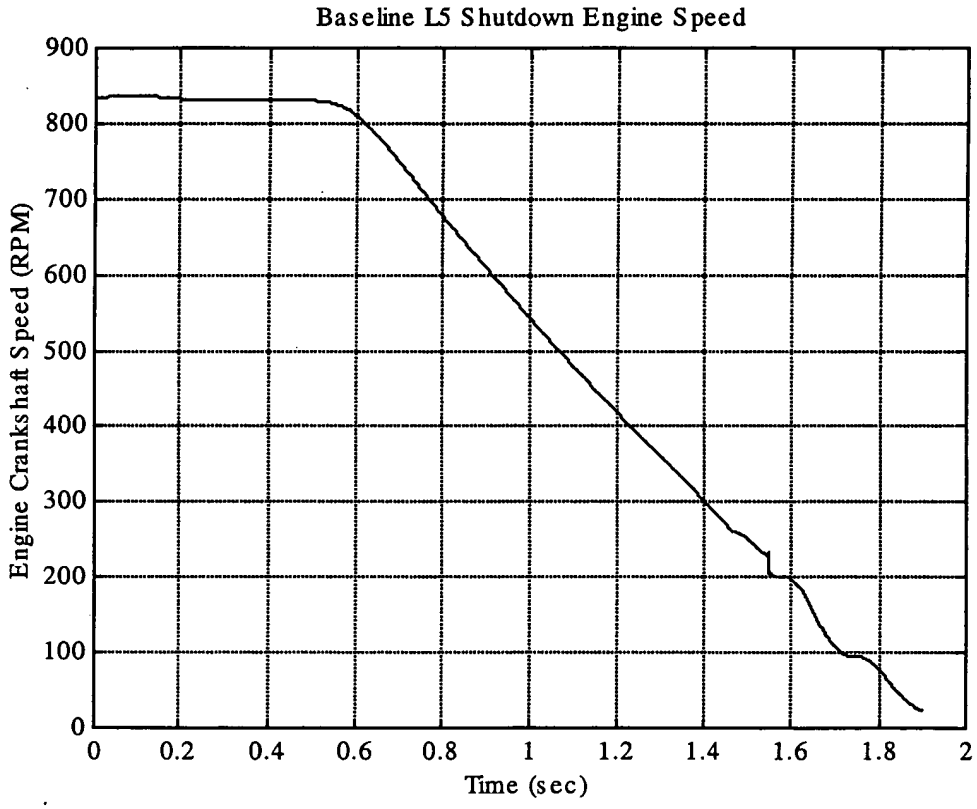
- **L5 Manual Has Shutdown Problems**
- **Processed Tucker's Data**
  - 300 RPM, 12.5 Hz Driveline Resonance
    - » Shutdown Gear Rattle
  - 180 RPM, 7.5 Hz Engine Mode(s)
    - » Shutdown Wiggle
    - » Soft Mounts for Isolation
  - Supports Under Oil Pan (Constrained Roll)
    - » Greatly Reduced Wiggle
    - » Slightly Reduced Rattle (Case Accelerations)
      - Likely a Case Resonance Change
      - Perhaps a Slight Torsional Resonance Change

Randy Beikmann
8-341-3793

GM General Motors
Noise & Vibration Center

L5 Shutdown
Time Trace of RPM

NVC

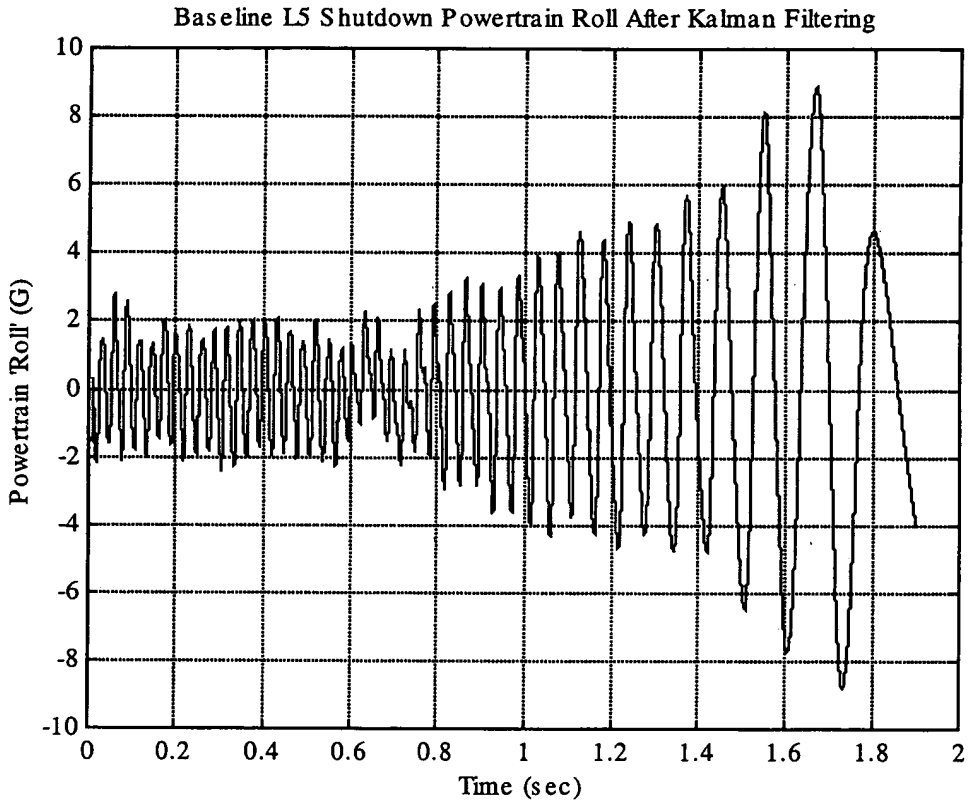


Randy Beikmann
8-341-3793

General Motors
Noise & Vibration Center

L5 Shutdown
Time Trace of Powertrain Roll

NVC

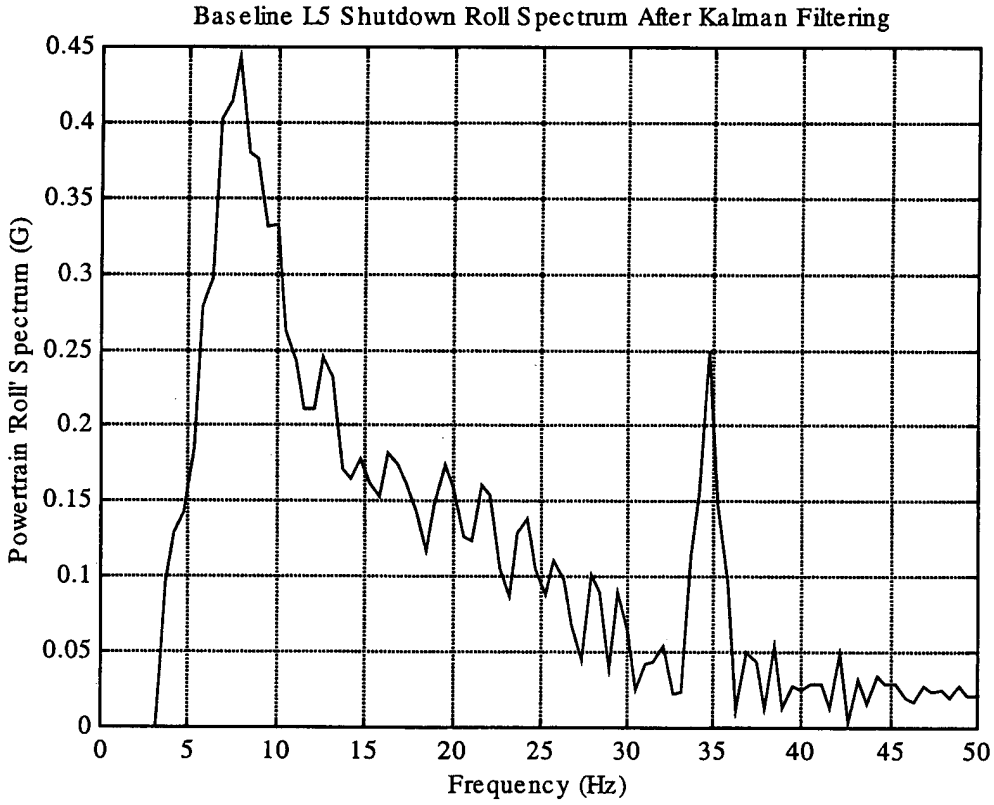


Randy Beikmann
8-341-3793

General Motors
Noise & Vibration Center

L5 Shutdown
Powertrain Roll Frequency Spectrum

NVC



Randy Beikmann
8-341-3793

GM General Motors
Noise & Vibration Center

L5 Shutdown N&V
Solution

NVC

- **Shutdown Seemed Long**
  - Other Vehicles Shut Down Faster
    - » Low Friction? Bigger Flywheel?
  - Brainstormed Ways to Quicken Shutdown
    - » Leave Alternator On
    - » Turn A/C Compressor On
- **Tucker and I Had Discussion With Slopsema**
  - Tom Mentioned Throttle Opens to 20% on Shutdown
    - » Limp-Home Mode for Electronic Throttle Control
    - » Essentially Wide-Open for Idle Air Requirements
  - Hurts Shutdown Two Ways
    - » No Throttling Loss to Decelerate Engine
      - More Time to Excite Resonances
    - » Compressing Atmospheric Instead of Low Pressure Air
      - Bigger Torque Pulses to Excite Resonances

Randy Beikmann
8-341-3793

GM General Motors
Noise & Vibration Center

L5 Shutdown N&V
Solution

NVC

- **Tried Other Shutdown Procedures**
  - Slopsema Closed Throttle w/Screwdriver
    - » Quick Shutdown
    - » No Noticeable Rattle or Wiggle
  - I Pulled Fuel Injector Fuse
    - » Minor Rattle and Wiggle
    - » PCM Opened Throttle, Attempting to Maintain Idle Speed
- **Recommendation**
  - Shut Throttle Completely(?) for One Second After Key-Off
    - » Could Cause a Post-Shutdown "Snort"
  - Other Groups Want This Now
  - Bruce Submitting PRF for Shutdown Spec's
- **Good Example of Changing Assumptions With New Technology**
  - I Never Thought to Ask if Throttle Was Open on Shutdown, They Never Thought to Tell

Randy Beikmann
8-341-3793

GM General Motors
Noise & Vibration Center

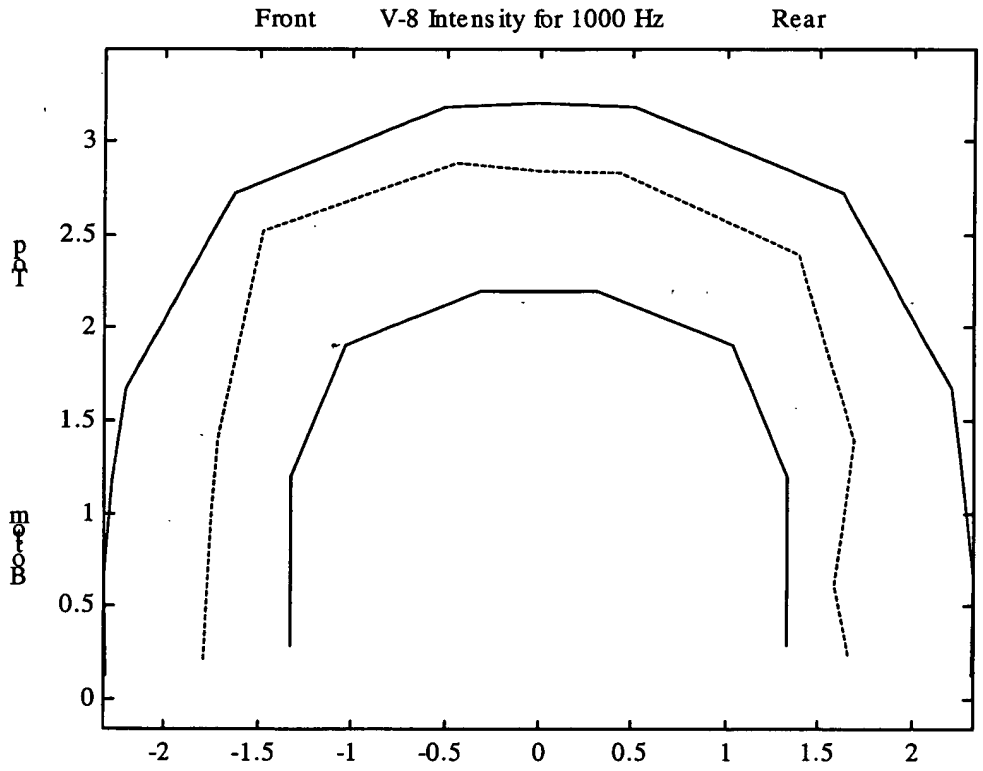
Other Projects

- **Noise and Vibration Data Base (NVDB)**
  - Parameter List Finalized
  - Need to Pick Mandatory Fields
- **Gear Rattle/Driveline Modeling**
  - Consulting w/Emmanuel Bediako
- **Sound Source Project (w/Grimmer)**
  - Measured Two Engine/Cell Combinations
  - Still Processing Data
    - » Reactivity High In L-6 Cell
      - May be Engine Radiation Pattern

Randy Beikmann
8-341-3793

Radiation Pattern Program
Gen3 V-8, 1000 Hz, 60-80 dB(A) Range

NVC



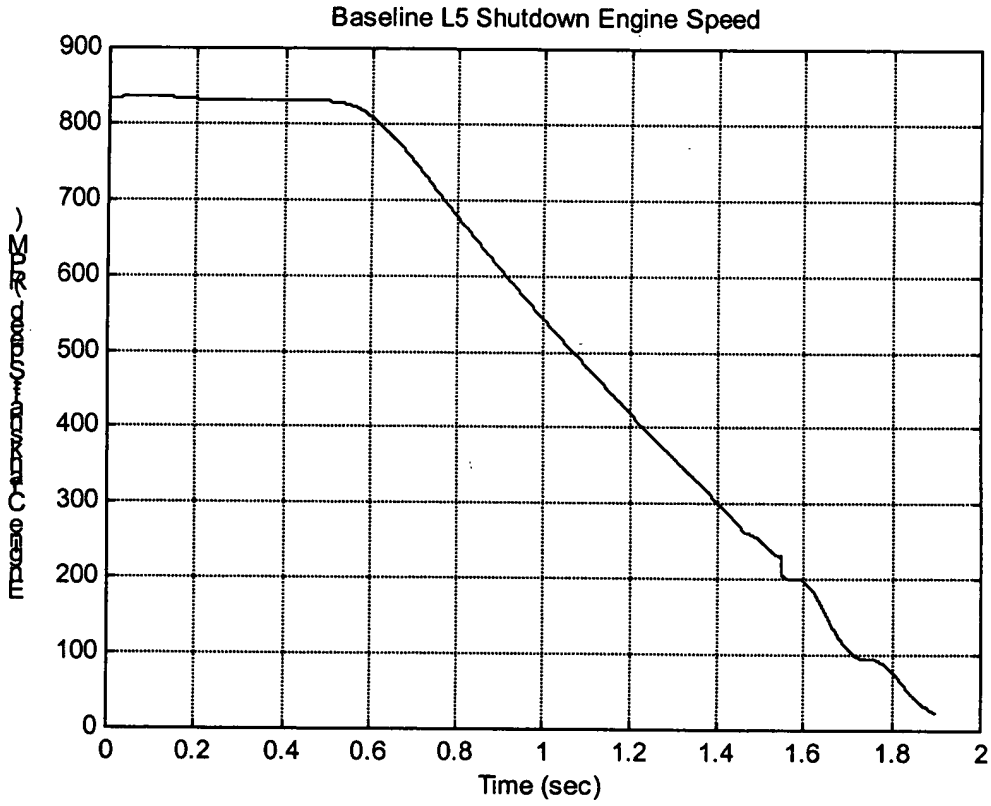
Randy Beikmann
8-341-3793

General Motors
Noise & Vibration Center

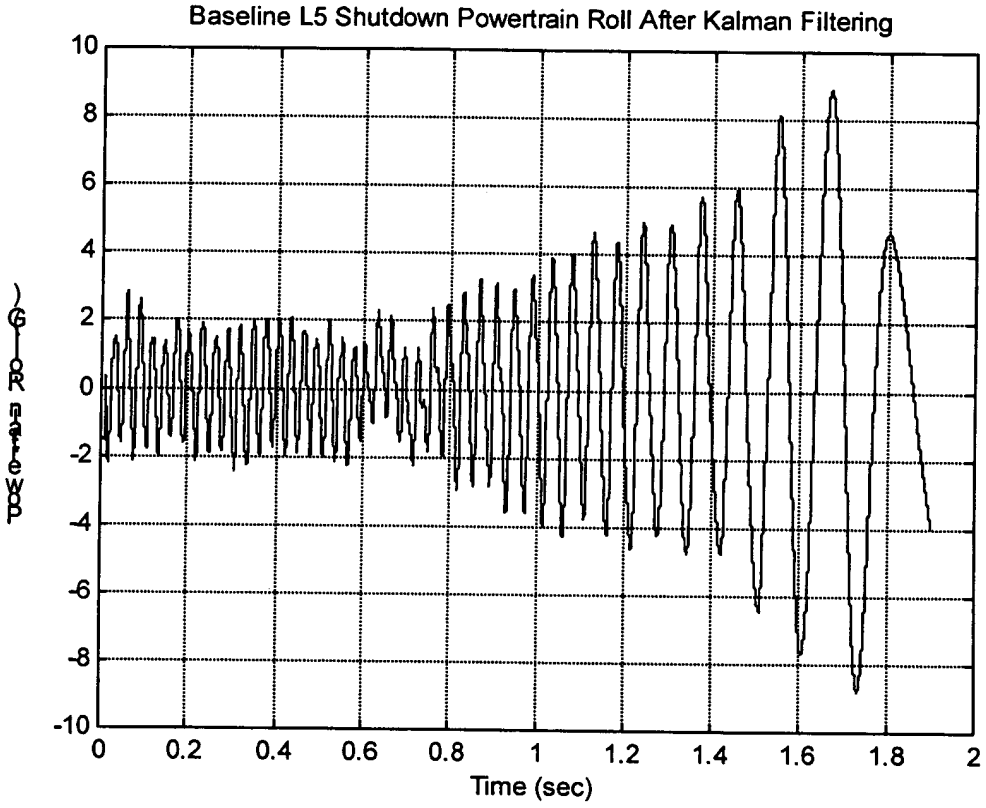
The following data is from a baseline L5 in a truck during shutdown. The first goal was to assess the cause of the shutdown wiggle (extreme engine motion on shutdown). The second was to assess whether the wiggle is related to the gear rattle. The data were taken by Bruce Tucker. The analysis and this summary are by Randy Beikmann.

I first tried CASM analysis on the 13 seconds of "steady state" data before shutdown to try to identify the mounting resonances of the powertrain. Because of the short length of data and excessive RPM variation, no significant conclusion could be formed.

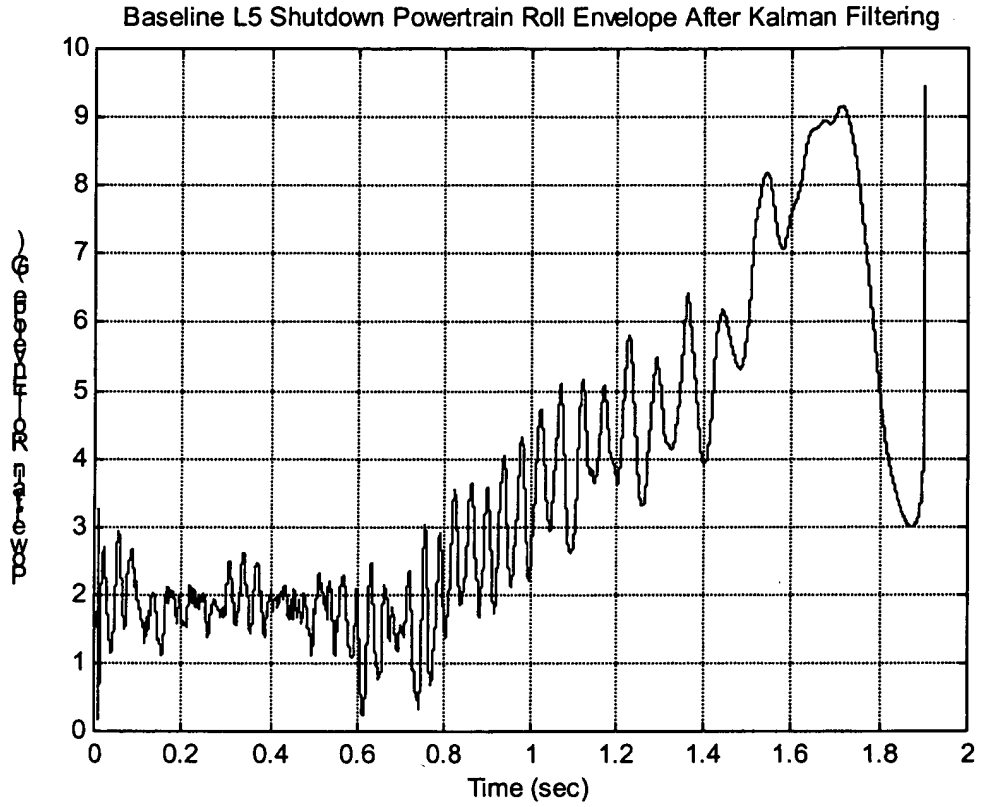
Looking then in the time domain, I concentrated on the 2 seconds shown below (about 0.5 seconds of steady operation at 830 RPM and 1.4 seconds of shutdown. The first thing to note is how smooth and linear the slow-down of the engine is, until about 240 RPM, when compression torque is at a low enough frequency to significantly accelerate the crank. Because of this linearity, an equal amount of time is spent sweeping through all speeds below idle.



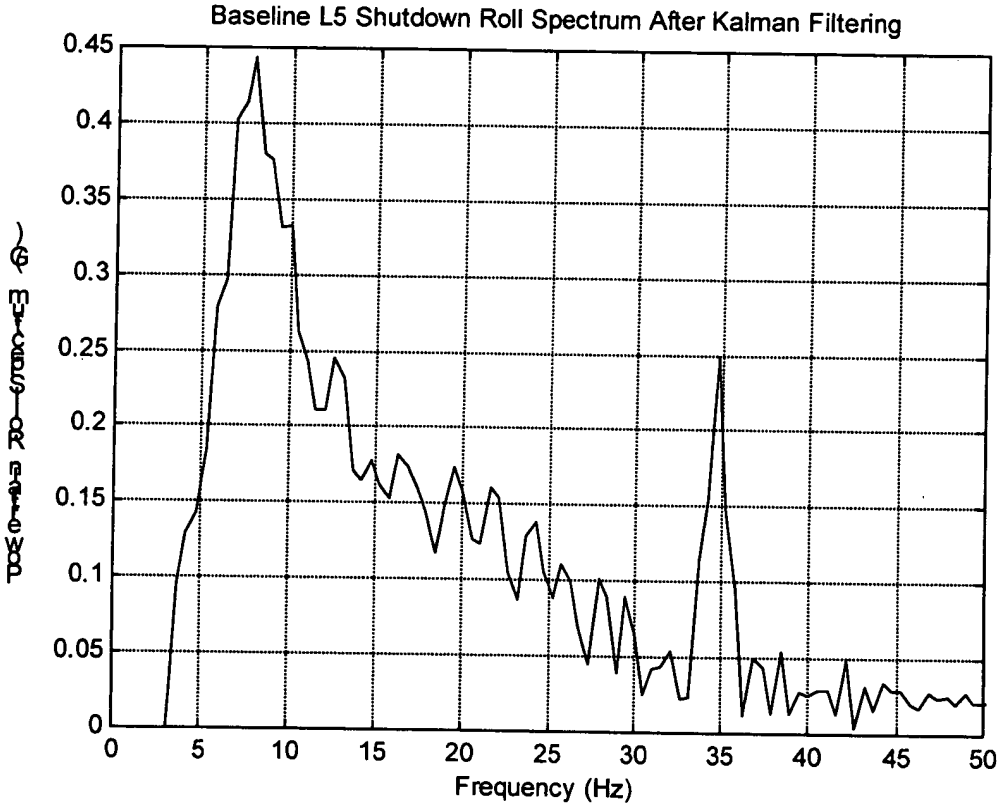
Next is a trace of the powertrain 'roll' (actually the difference between two vertical accelerometers spaced laterally across the engine). This trace has been high passed at 3 Hz, low passed at 30 Hz, and a wide Kalman filter tracking 2.5 engine order. One can see that as time increases (and RPM decreases) the roll acceleration gets larger, indicating the approaching of a resonance. Note that growing accelerations at lower speeds (and lower frequencies) correspond to even faster growing displacements, since acceleration is proportional to displacement times the square of frequency.



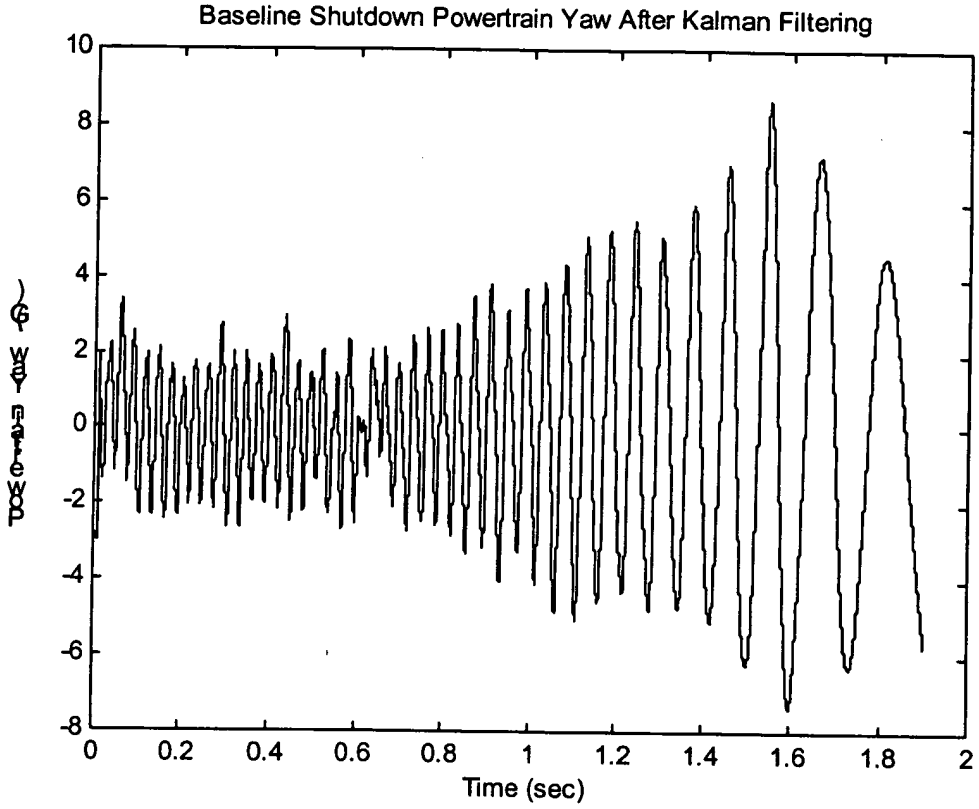
The next figure is of the powertrain roll envelope. One can see that it grows until the time of 1.7 seconds, which corresponds to 100 RPM. This does not necessarily mean that 2.5 order at this speed (2.5 X 100 / 60 = 4.2 Hz) is the powertrain mounting frequency, since part of the vibration may be after-ring from the actual on-resonance excitation.



This figure shows the spectrum of the roll vibration measured in the previous figures. It has a definite component corresponding to 2.5 order at the nominal idle speed (830 rev/min X 2.5/rev X 1min/60 sec = 34.5 Hz) previous to shutdown. It then has increasing content as frequency decreases until reaching a peak at about 7.5 Hz. Because of the linear nature of the speed sweep, I believe that the peak in the response at 7.5 Hz corresponds to the powertrain mounting resonance for roll. Also worth noting is the height of the 7.5 Hz peak relative to the 34.5 Hz peak, even though much less time was spent sweep through 7.5 Hz than at 34.5 Hz (where the engine operated steady for 0.5 seconds). This is another indication of resonance.

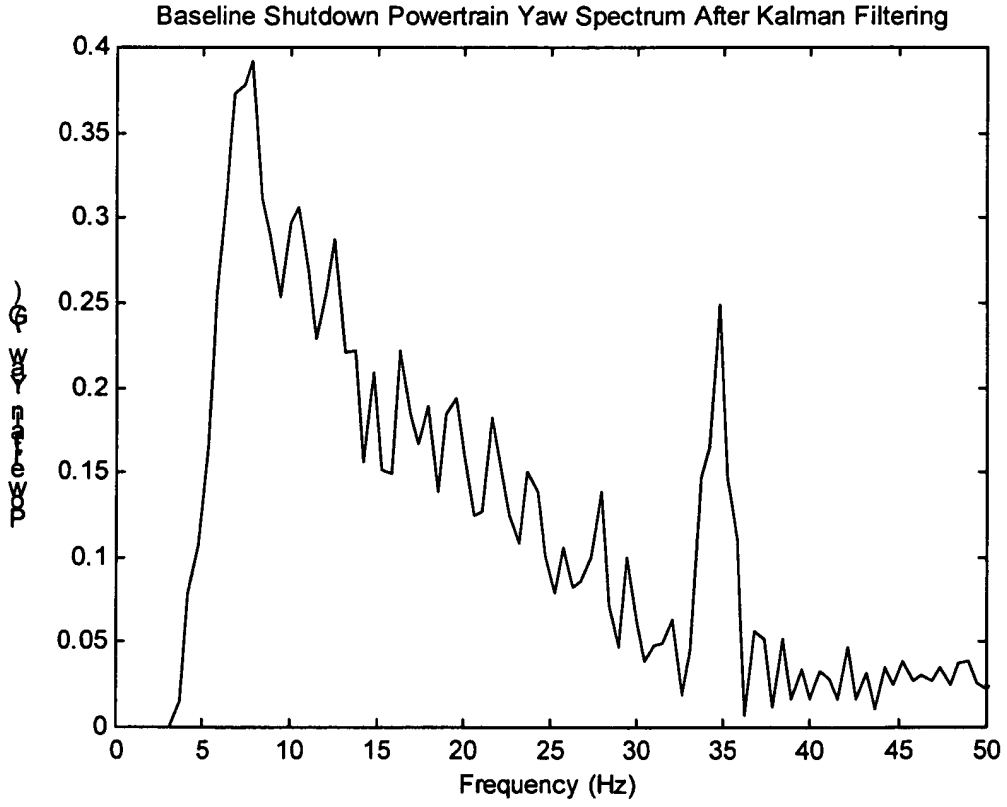


This figure shows the yaw motion of the engine during the same shutdown event. Comparison between this and the first figure shows that the yaw and roll motions are very similar, almost with the same amplitude and phase. This suggests a high degree of coupling between the yaw and roll degrees of freedom.

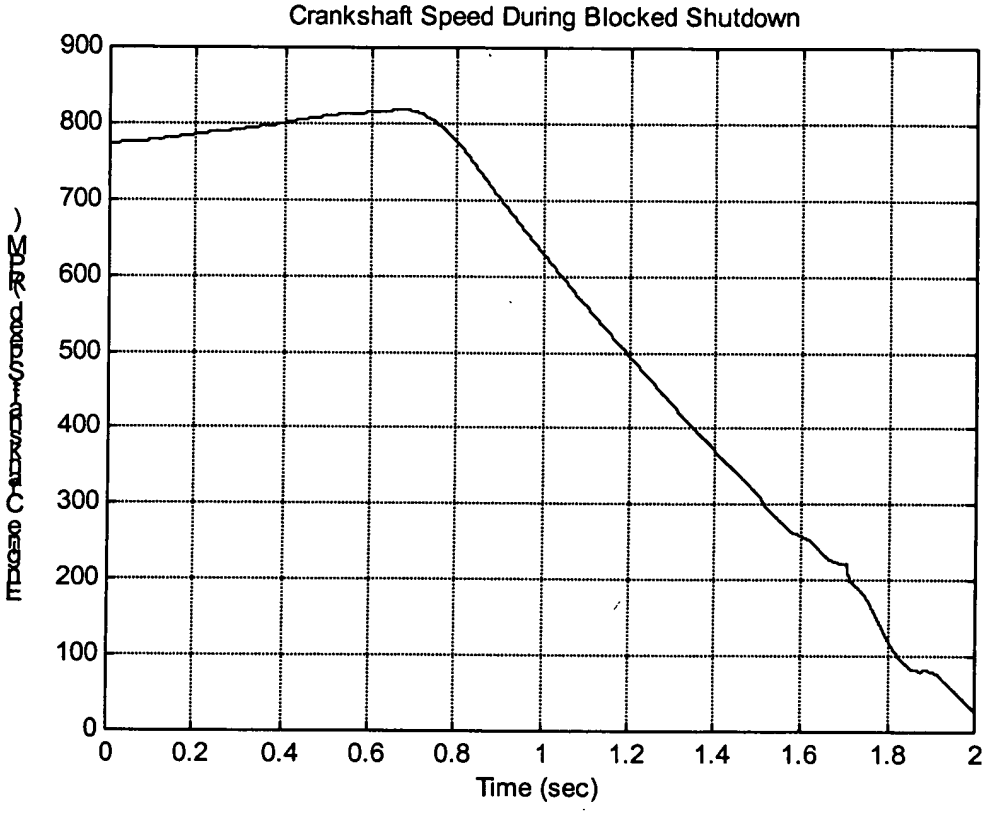


This figure is the frequency spectrum of the above yaw trace. Note that there is a peak at the 2.5 order frequency at nominal idle, as in the roll data. Again, during shutdown, the spectrum shows a large peak at 7.5 Hz (the same as for the roll) with amplitude nearly the same as for roll. This is further indication that the yaw and pitch DOF's are coupled. This could mean one of two things. There could be a single roll/pitch mode at 7.5 Hz with a fore-aft nodal line at roughly a 45-degree angle to horizontal (not likely due to mount placement). There could exist a pair of somewhat pure yaw and roll modes, but at nearly the same frequency. They could even be degenerate modes with essentially the same frequency, and no clear nodal lines. With this highly coupled situation, roll input energy (from the crankshaft gas compression torque) can easily be fed not only into the roll DOF, but also the yaw DOF.

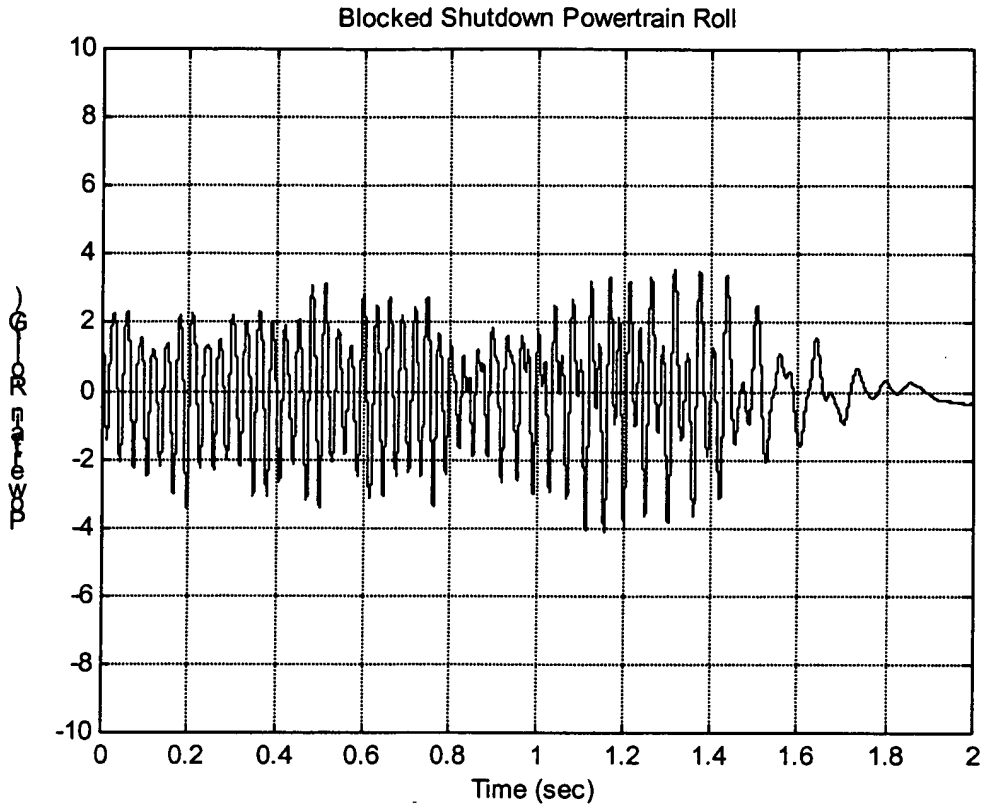
These modes (and DOF's) could be decoupled by changing the relative stiffness of the engine and transmission mounts. Increasing the lateral rate of the transmission mount would help by increasing the yaw mode frequency while having little effect on the roll mode frequency. This should de-sensitize the yaw mode to the roll input. Stiffening all the mounts should reduce the motion because of the higher corresponding natural frequencies (with degradations in structure-borne noise).



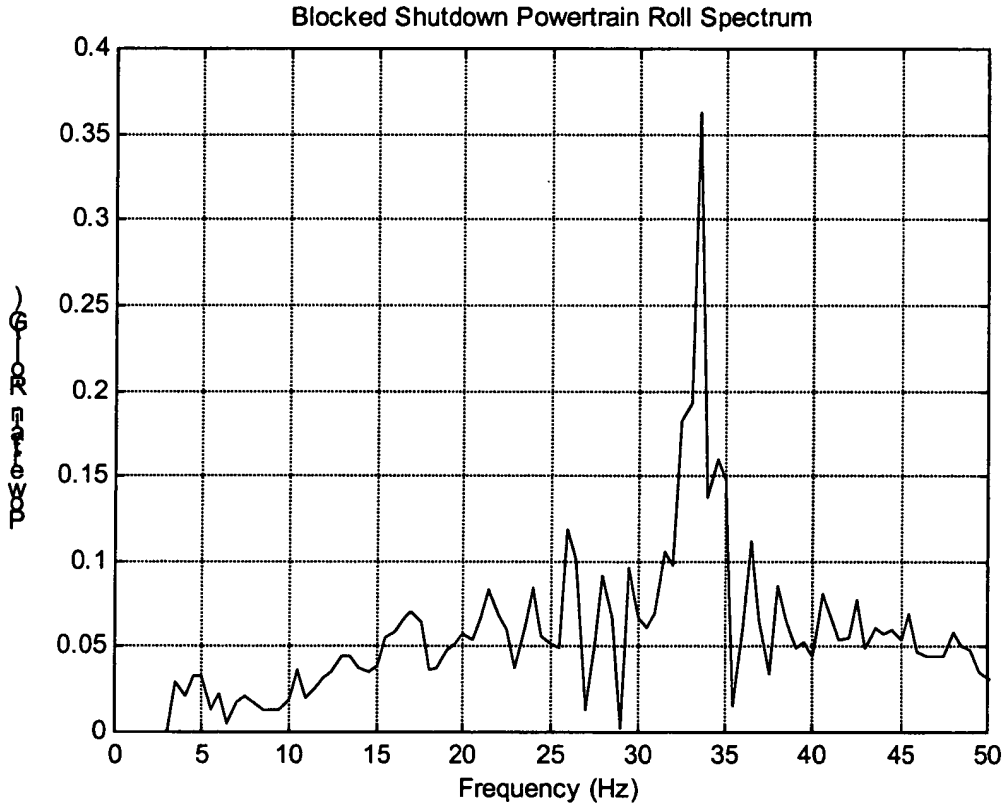
The next condition is the "blocked" condition, where Bruce Tucker put a block of wood under the engine to constrain its roll. The following plot is the RPM trace during that shutdown (0.7 seconds of nominal idle and 1.3 seconds of shutdown).



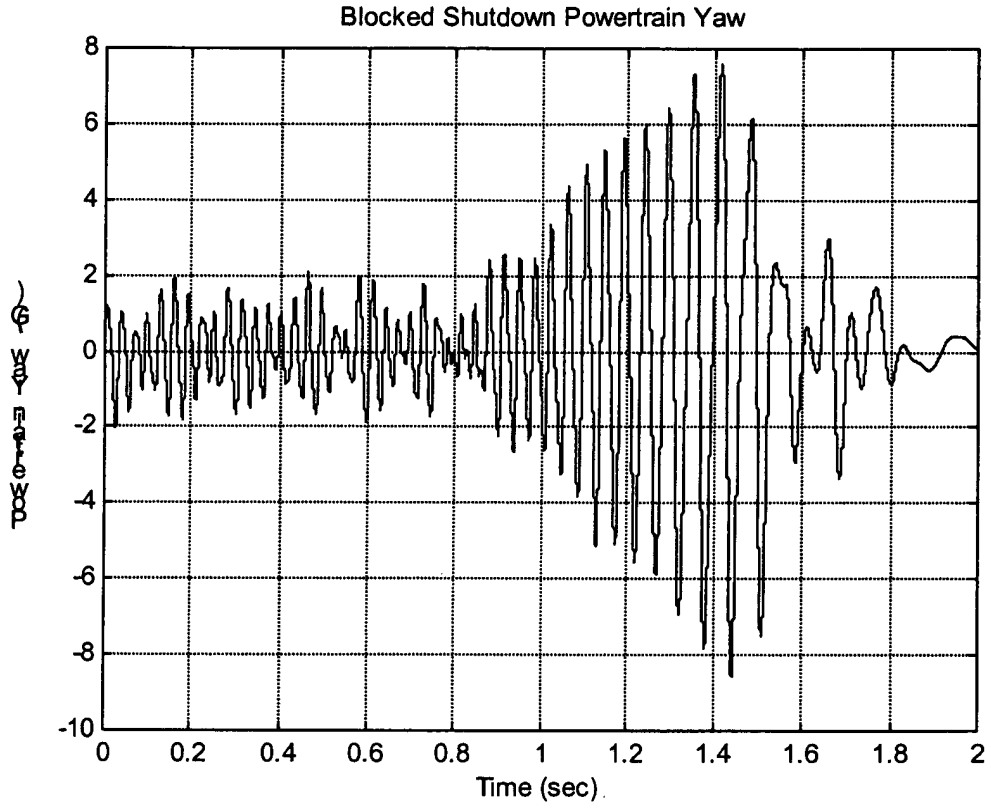
The following is the roll trace in this condition. The roll amplitude is much lower than in the baseline condition, and at a higher frequency.



This plot shows the spectrum of the powertrain roll in the blocked condition. As before, there is a peak at 34.5 Hz, 2.5 order at nominal idle. However, no prominent peak occurs below this frequency from the shutdown excitation. Evidently the roll mode is much higher in frequency than before (not surprising considering the modification!), maybe even 35 Hz.



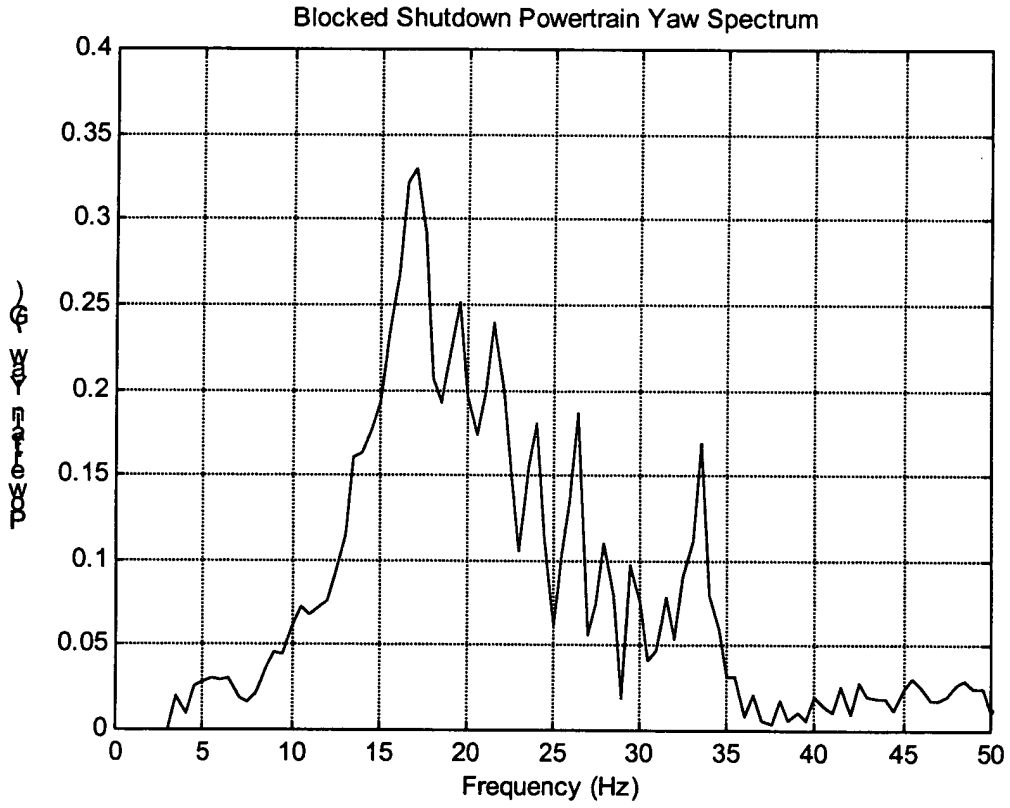
Because of the way the block contacted the oil pan, it added less stiffness to yaw than to roll. As such, the yaw motion looks fairly similar in amplitude to the baseline condition.

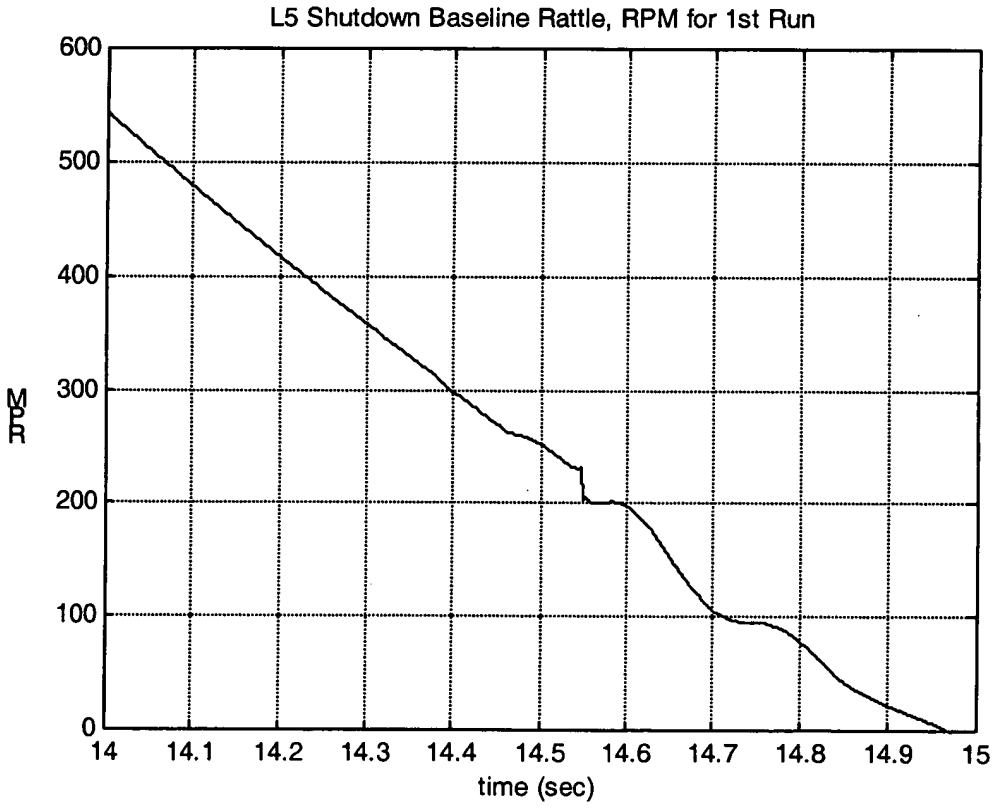


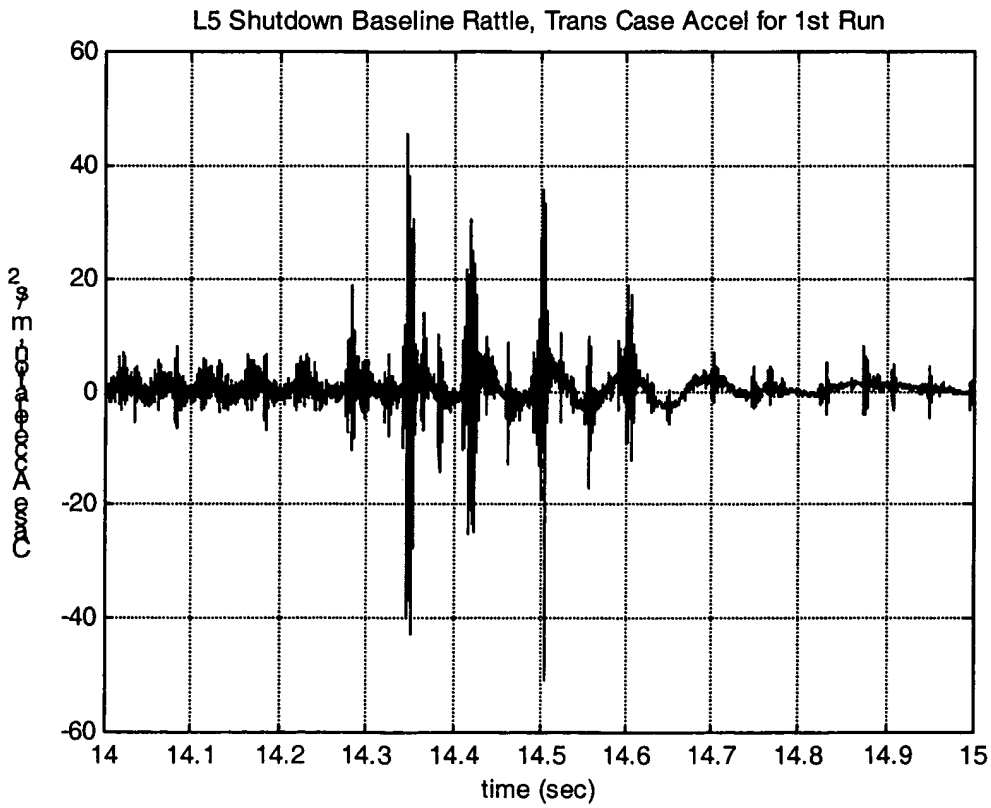
It appears, however, that the yaw mode has increased appreciably in frequency, to about 17 Hz.

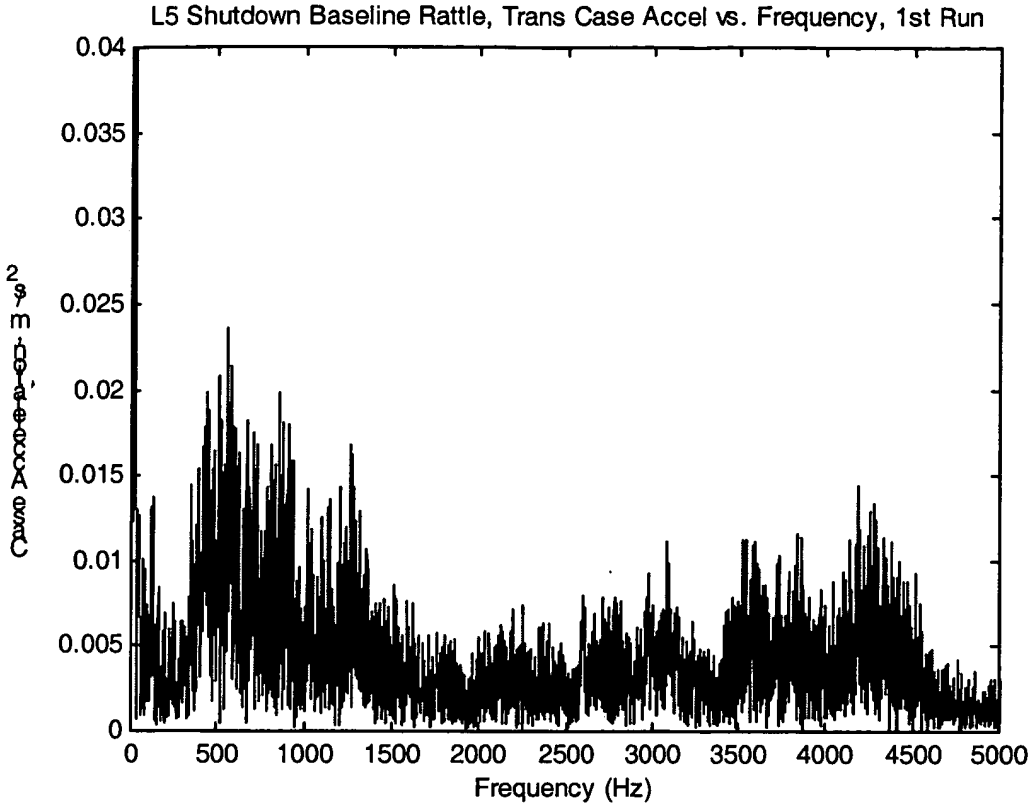
Bruce's comments on this run were that no "wiggle" existed on shutdown, but the gear rattle was still there. This confirms our suspicion that the wiggle and the gear rattle are two unrelated problems.

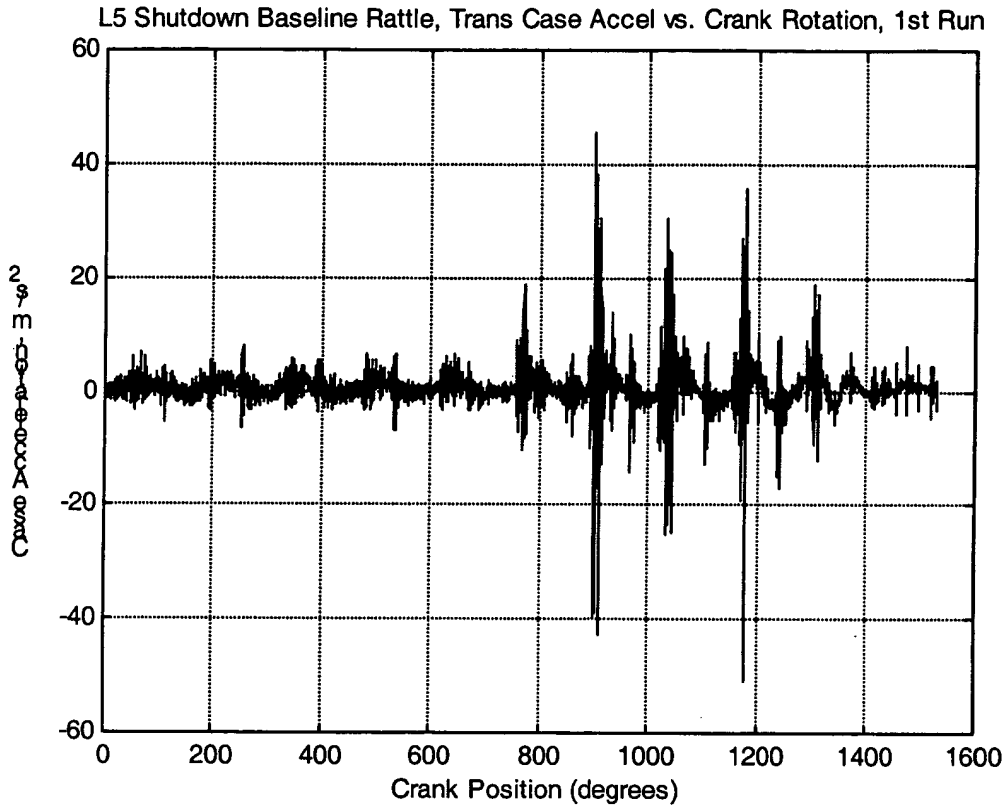
My judgment is that adding lateral stiffness to the mounting system is a good place to start in reducing the wiggle. That may at least decouple the yaw motion from roll input, reducing the powertrain yaw motion and probably lateral seat track motion.

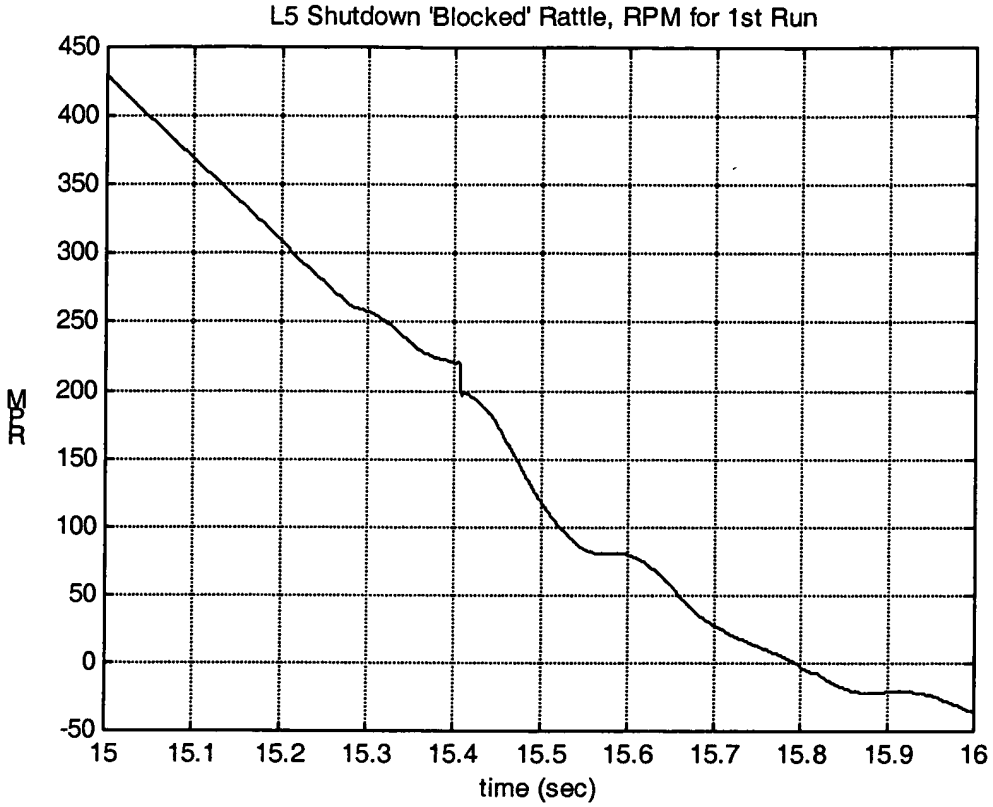


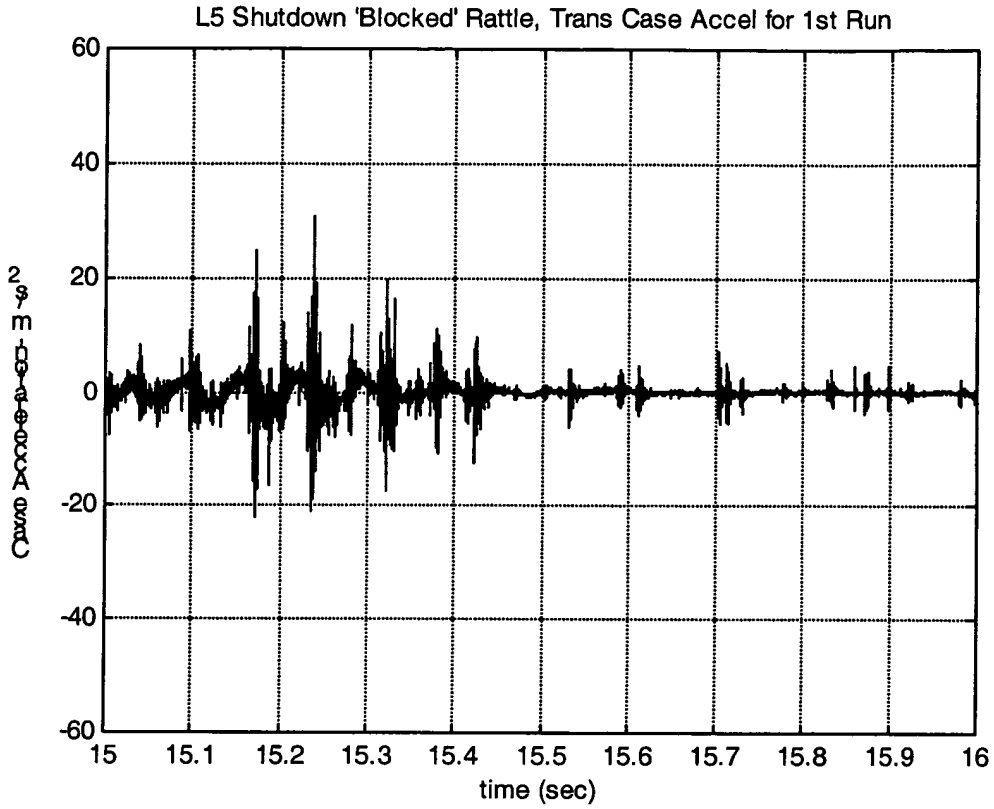

L5 Shutdown Baseline Rattle, RPM for 1st Run
600
500
400
300
200
100
0
RPM
14
14.1
14.2
14.3
14.4
14.5
14.6
14.7
14.8
14.9
15
time (sec)

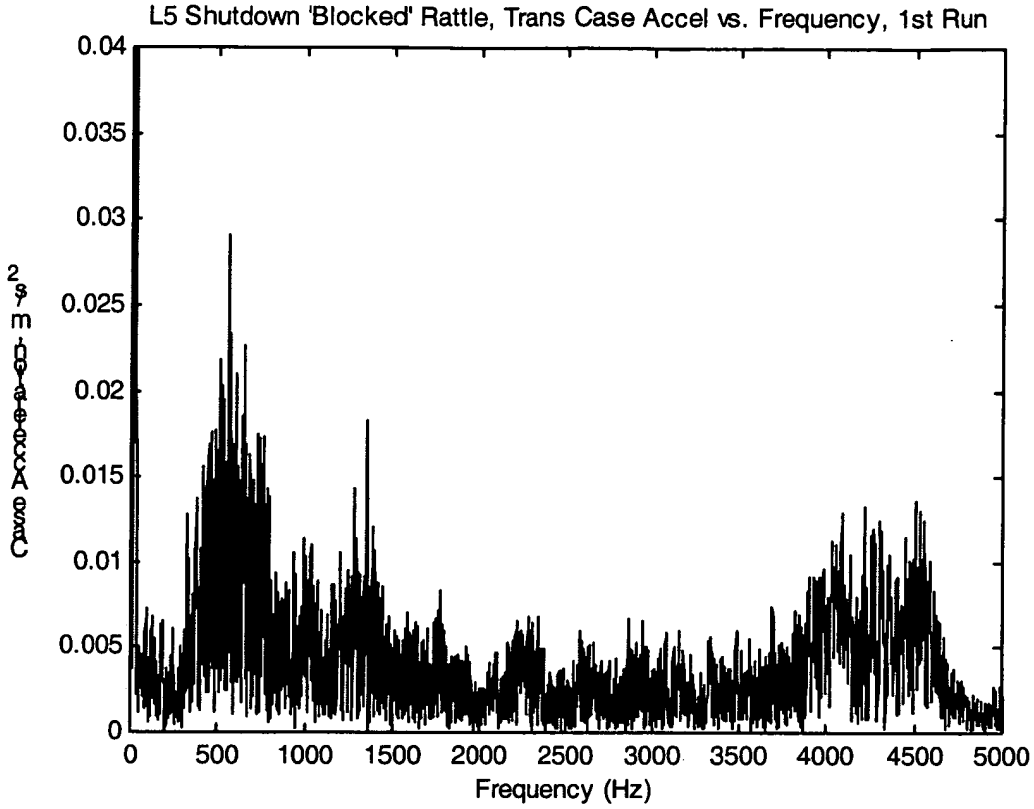

L5 Shutdown Baseline Rattle, Trans Case Accel for 1st Run
60
40
20
0
-20
-40
-60
14
14.1
14.2
14.3
14.4
14.5
14.6
14.7
14.8
14.9
15
time (sec)

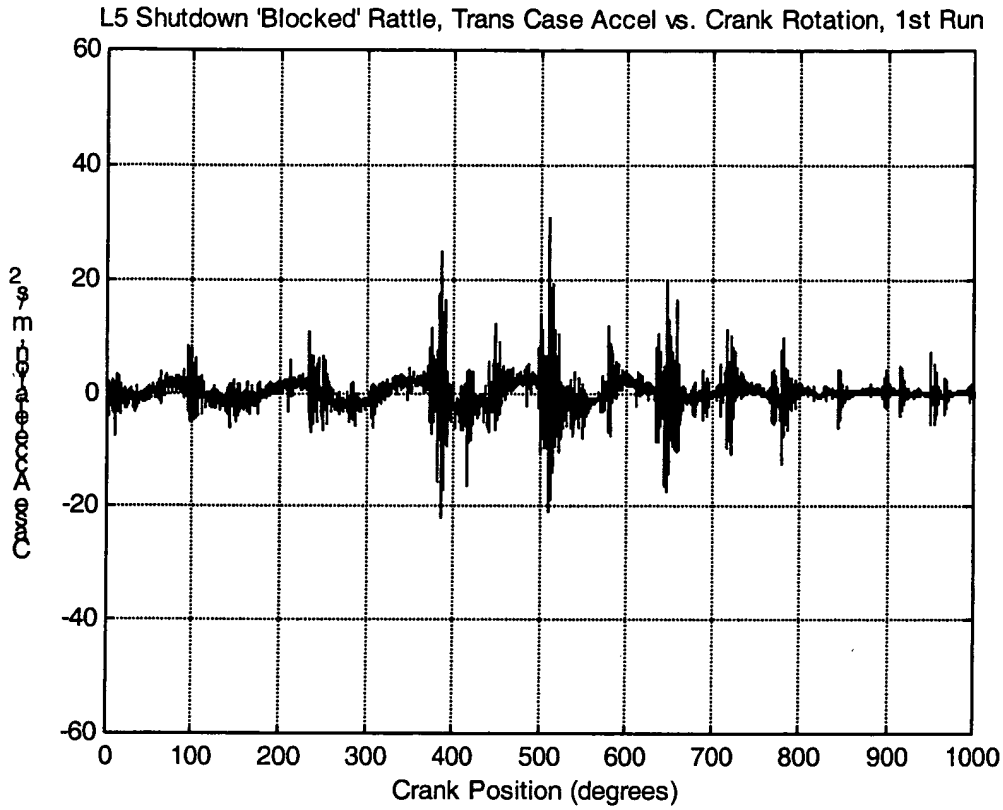

L5 Shutdown Baseline Rattle, Trans Case Accel vs. Frequency, 1st Run
0.04
0.035
0.03
0.025
0.02
0.015
0.01
0.005
0
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
Frequency (Hz)


L5 Shutdown Baseline Rattle, Trans Case Accel vs. Crank Rotation, 1st Run
60
40
20
0
-20
-40
-60
0
200
400
600
800
1000
1200
1400
1600
Crank Position (degrees)


L5 Shutdown 'Blocked' Rattle, RPM for 1st Run
450
400
350
300
250
200
150
100
50
0
-50
RPM
15
15.1
15.2
15.3
15.4
15.5
15.6
15.7
15.8
15.9
16
time (sec)


L5 Shutdown 'Blocked' Rattle, Trans Case Accel for 1st Run
60
40
20
0
-20
-40
-60
15
15.1
15.2
15.3
15.4
15.5
15.6
15.7
15.8
15.9
16
time (sec)


L5 Shutdown 'Blocked' Rattle, Trans Case Accel vs. Frequency, 1st Run
0.04
0.035
0.03
0.025
0.02
0.015
0.01
0.005
0
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
Frequency (Hz)


L5 Shutdown 'Blocked' Rattle, Trans Case Accel vs. Crank Rotation, 1st Run
60
40
20
0
-20
-40
-60
0
100
200
300
400
500
600
700
800
900
1000
Crank Position (degrees)